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A Statistical Analysis of Coal Mine Fire Incidents in the United States From 1950 to 1977

By L. Bruce McDonald and William H. Pomroy

UNITED STATES DEPARTMENT OF THE INTERIOR

I 28.27:

Information Circular 8830

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UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES
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This publication has been cataloged as follows:

McDonald, L Bruce

A statistical analysis of coal mine fire incidents in the United States from 1950 to 1977.

(Information circular - Bureau of Mines ; 8830)
Supt. of Docs. no.: I 28.27:8830.

1. Coal mines and mining–United States–Fires and fire prevention–Statistics. I. Pomroy, William H., joint author. II. Title. III. Series: United States. Bureau of Mines. Information circular ; 8830.

TN295.U4 [TN315] 622s [363.3'79] 79-607921

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A STATISTICAL ANALYSIS OF COAL MINE FIRE INCIDENTS IN THE UNITED STATES FROM 1950 TO 1977

by

L. Bruce McDonald[1] and William H. Pomroy[2]

ABSTRACT

This Federal Bureau of Mines publication is a statistical analysis of all surface and underground coal mine fires reported in the United States from 1950 to 1977. Accounts of selected nonreportable fires and opinion data gathered via interviews with mine safety directors were separately analyzed. Both reported and nonreportable fires were analyzed by time trends, State, ignition source, burning substance, location in mine, equipment, detection, duration, injuries, fatalities, and successful extinguishing agents. It was found that the majority of all mine fires were electrical in origin. The equipment most frequently involved in underground fires was conveyor belts, and in surface fires, it was crushers and/or breakers. Underground fires occurred most often near the working face. Water and hand-portable extinguishers were the most common methods of extinguishment.

INTRODUCTION

Fire is one of the most serious hazards in underground mining, for an underground fire can fill a mine with deadly carbon monoxide in minutes. This high contamination rate, coupled with the long periods of time needed to evacuate personnel from an underground mine, creates, in even a moderately sized fire, a significant potential for death and injury. Surface fires, both in structures and on equipment, are also a serious safety hazard.

Recognizing the severity of these hazards, the mining industry and the Mine Safety and Health Administration (MSHA) have taken important steps to help prevent such fires and to minimize their effects when they occur. The efforts of these bodies could be significantly enhanced if a detailed, comprehensive, and well-documented coal mine fire data base were available. Despite the extensive amount of information pertaining to actual fires and related incidents, which already exist in various official files and periodicals, until now no systematically organized and annotated bibliography of the material has existed. In 1978, the Allen Corp. of America, in Orlando, Fla., under contract to the Federal Bureau of Mines, gathered and analyzed all

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published data and unpublished reports in official files and interviewed selected mine safety personnel to develop an annotated bibliography of coal mine fires.[3] This report describes the contractor's data acquisition and analysis procedures, provides results of the analysis, and discusses conclusions and recommendations. This report provides a detailed, comprehensive, and well-documented data base on coal mine fires that is useful when dealing with this important mine safety problem.

DATA ACQUISITION PROCEDURES

Data on specific coal mine fire incidents were acquired from three major areas: publications, MSHA fire reports, and mine safety directors. Each of these areas is discussed separately below.

Publications

An extensive literature search was conducted to obtain data on specific mine fires. In addition to the Engineering Index and other reference documents, the following publications were searched:

1. Canadian Institute of Mining Bulletin
2. Canadian Mining and Metallurgical Bulletin
3. Canadian Mining and Metallurgy
4. Canadian Mining Journal
5. Canadian Society of Civil Engineers
6. Charleston (S.C.) Gazette
7. Coal Age
8. Coal and Coal Trade Journal
9. Coal Mining
10. Coal Mining & Processing
11. Denver Post
12. Excavating Engineer
13. Iron and Coal Trades Review
14. Journal of Mines, Metals & Fuels
15. Mechanization
16. MESA: The Magazine of Mining Health & Safety
17. Mines Magazine
18. Mining Congress Journal
19. Mining Engineering
20. Morgantown Dominion Post
21. New York Times
22. Pittsburgh Press
23. Safety News
24. U.S. Bureau of Mines publications: Bulletins, Information Circulars, Minerals Yearbooks, Miners Circular, and Technical Papers

[3]McDonald, L. B., and R. M. Baker. An Annotated Bibliography of Coal Mine Fires (Contract No. J0275008). BuMines Open File Rept. 7(1)--(3)-80, 1979, 1147 pp.; available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Pittsburgh, Pa., and Spokane, Wash.; U.S. Department of Energy facilities in Carbondale, Ill., and Morgantown, W. Va.; National Mine Health and Safety Academy, Beckley, W. Va.; and National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C. Order from National Technical Information Service, Springfield, Va., PB 80-140205 (set).

In general, results of the literature search were disappointing. Although newspapers provided a large number of reports on major mine fires, most of the articles were sensational rather than technical. Journal articles and Bureau of Mines publications tended to address firefighting techniques and equipment, but they seldom contained usable data on specific mine fires. However, 22 articles containing useful data were located.

MSHA Reports

The primary data source was MSHA fire reports contained in the files of MSHA coal mine health and safety district and subdistrict offices. Fire report files were searched at all MSHA district offices and the Health and Safety Analysis Center in Denver, Colo. Except for Price, Utah, and Princeton and Madison, W. Va., which did not maintain separate filing systems from their district office, files at all MSHA subdistrict offices were searched.

The MSHA district and subdistrict offices included in the survey were--

1. District 1--Wilkes-Barre, Pa.
2. District 2--Pittsburgh, Pa.
3. Monroeville Subdistrict--Monroeville, Pa.
4. District 3--Morgantown, W. Va.
5. District 4--Mt. Hope, W. Va.
6. Mt. Hope Subdistrict--Mt. Hope, W. Va.
7. District 5--Norton, Va.
8. Norton Subdistrict--Norton, Va.
9. Richlands Subdistrict--Richlands, Va.
10. District 6--Pikeville, Ky.
11. District 7--Barbourville, Ky.
12. Barbourville Subdistrict--Barbourville, Ky.
13. Birmingham Subdistrict--Birmingham, Ala.
14. District 8--Vincennes, Ind.
15. Benton Subdistrict--Benton, Ill.
16. St. Clairsville Subdistrict--St. Clairsville, Ohio
17. District 9--Denver, Colo.
18. Denver Subdistrict--Denver, Colo.
19. McAlester Subdistrict--McAlester, Okla.
20. District 10--Madisonville, Ky.
21. MSHA Field Office--Hazard, Ky.
22. Health and Safety Analysis Center--Denver Federal Center

At each MSHA office, all accident report files on fires, explosions, and ignitions were searched. Only reports on fires were utilized, but other reports were reviewed to locate any incorrectly filed or titled reports. A total of 1,014 underground mine fire reports and 188 surface mine fire reports were located.

Mine Safety Directors

MSHA regulations require that fires lasting 30 min or more or fires involving an injury must be reported. Each reported fire is investigated by an MSHA inspector, who then prepares a fire report. Noninjury fires under

30 min are not reportable, and, consequently, no official fire report exists. However, many short-duration fires were reported as a courtesy, and others were investigated by the inspectors after hearing about the fire from a third party. As a general rule, these short-duration fire reports were found at MSHA subdistrict offices in the form of internal memoranda.

To develop a data base that represented mine fires in general, a number of mine safety directors were interviewed to gather data on nonreportable mine fires. Fourteen local and regional safety directors in charge of 38 surface mines and 37 underground mines were interviewed to obtain descriptions of nonreportable mine fires at their mines over the last 5 years. The directors related a number of nonreportable fires and provided internal company memoranda on many of these fires. Nonreportable fire descriptions developed as a result of these interviews were analyzed separately from the reported fires.

When gathering data on rare events such as fires, it is often advisable to also ask knowledgeable individuals to give hazard opinion data. Consequently, after the mine safety directors related their nonreportable fire data, they were asked to rank various causes, ignition sources, burning substances, and equipment as to their possible involvement in a nonreportable fire.

DATA ANALYSIS

The data were analyzed in three different sets: Reportable Fires, Nonreportable Fires, and Opinion Data. Individual data tabulations were analyzed for statistical significance where such analysis would contribute to a better understanding or a more efficient utilization of the data. Correlations between sets of data were determined by calculating the Spearman's rho rank order correlation coefficient. Each data value from the two sets to be correlated was assigned a ranking depending on its numerical value, with the highest value being assigned a ranking of 1, the second highest value a ranking of 2, and so on. Spearman's rho was then calculated according to the formula--

$$\rho = 1 - \frac{6 \sum_{i=1}^{N} (x_i - y_i)^2}{N(N^2 - 1)} \qquad (1)$$

where ρ = Spearman's rho,

x_i = rank of data value,

y_i = rank of data value,

and N = number of data values in each set.

The statistical significance of the correlation was determined by comparing the calculated value of rho to a theoretical distribution. Spearman's rho is particularly useful when the order of ranking of data is more important than the actual data value.

The chi-squared (χ^2) test was applied to determine whether the differences in values within a given data set were significant or whether such differences were caused by random variations. The value of χ^2 was determined by the equation--

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad (2)$$

where O_i = observed value in each category,

and E_i = expected value in each category.

Significant differences in data values (not caused by random variations) are indicated when computed χ^2 values exceed corresponding theoretical values of the χ^2 distribution.

Reportable Fires

Data for reportable fires--30 min duration or resulting in injury--were analyzed in two sets. Results are discussed under the headings of underground fires and surface fires. Throughout this section, fires and various related factors from 1950 to 1977 are analyzed in short, 2- to 3-year periods, and also over three major time periods, 1953-61, 1962-69, and 1970-77. These three major periods represent eras of progressively more stringent Federal mine safety laws.

Underground Fires

Time Trends

The first analysis was to determine time trend effects on the number of fires in each year. Table 1 contains fire incidents by year for underground mines. As shown in figure 1, there is a definite trend toward a high number of fires in 1961, followed by a decrease and stabilization around 1975. When this curve is compared with the coal production curve, it is apparent that production is not the underlying reason for the shape of the curve. Another possible reason for the shape of the curve may be that increased mechanization of the mines during the 1950's led to more fires, and once mechanization peaked, increased safety began to lower the fire rate. However, no relationship between mechanically loaded mines and fire incidents is evident in the figure. A third possibility is that the rise in reported fires during the 1950's is due to increased reporting instead of increased fires.

TABLE 1. - Underground fire incidents by year

Year	Underground fire incidents	Year	Underground fire incidents	Year	Underground fire incidents
1950.....	9	1960.....	69	1970.....	36
1951.....	11	1961.....	58	1971.....	10
1952.....	9	1962.....	41	1972.....	21
1953.....	26	1963.....	57	1973.....	17
1954.....	34	1964.....	52	1974.....	7
1955.....	49	1965.....	58	1975.....	13
1956.....	43	1966.....	40	1976.....	17
1957.....	61	1967.....	50	1977.....	8
1958.....	64	1968.....	47		
1959.....	54	1969.....	53	Total...	1,014

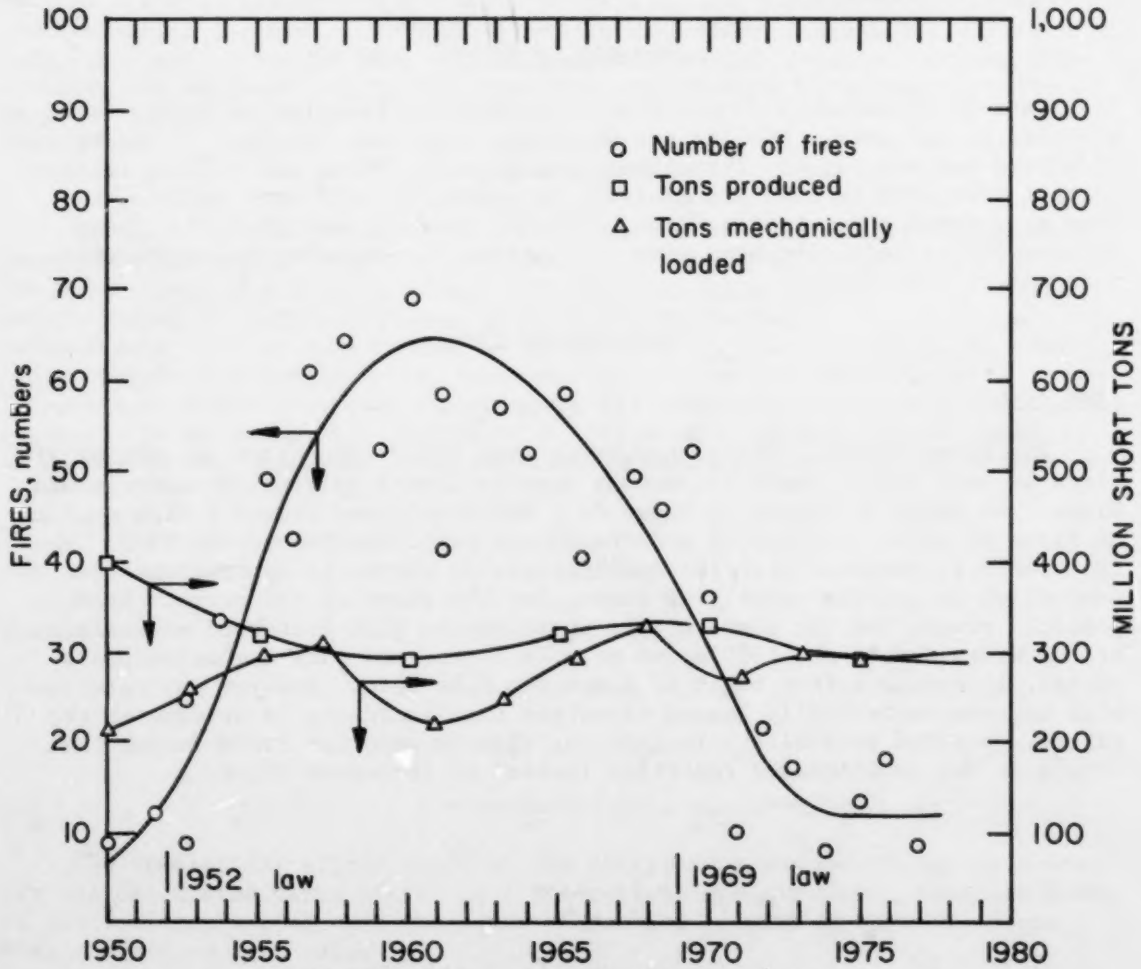

FIGURE 1. - Time trends for underground fires.

The apparent downward trend in fires since 1961 was tested to determine whether the trend was statistically significant. A rank order correlation between number of fires per year and date during the 1970-77 period yields a Spearman rho of -0.52, which is not statistically significant. The same correlation for the 1961-77 period yields a coefficient of -0.88, which is statistically significant at the 1-pct level. A chi-squared test of number of fires for each year during 1970-77 indicated a significant difference between values, indicating that they are not caused by random variation. Apparently, the 1961-77 fire data represent a significant downward trend that leveled off during the 1970-77 period. The leveling off is characteristic of most frequency data which cannot have a negative value and must stabilize above zero. There are significant differences between fire frequencies in the data from the 1970's, but they do not represent a significant downward trend. However, the frequency of fires in the 1970-77 period was significantly less than in the 1960-69 period. Whether this difference is a result of the 1969 law or is a continuation of the earlier trend is unclear.

Because fire data from 1970 until 1977 are most pertinent to current considerations, the analyses below concentrate on that time period.

Fires by State

Table 2 lists the number of fires in each State from 1970 to 1977. Although West Virginia, Pennsylvania, and Kentucky have the greatest number of fires, these States are also the top three in terms of production and consequently have greater exposure. The Spearman rank order correlation between each State's fire incident rank and production rank was found to be +0.84, which is highly significant.

TABLE 2. - Relative rankings of States in terms of fires, underground coal production, coal volatility, and fires per million tons mined, 1970-77

State	Fires			Underground coal production		Coal volatility		Fires per million tons	
	Number	Pct	Rank	Pct	Rank	Volatility	Rank	Fires	Rank
Alabama.....	2	1.6	9.5	2.5	7	34.4	11.5	0.034	10
Colorado.....	5	3.9	8	1.2	10	41.8	5.5	.185	4
Illinois.....	12	9.3	4	10.8	4	42.5	3	.048	9
Indiana.....	1	.8	11.5	.3	12.5	42.3	4	.137	5
Iowa.....	1	.8	11.5	.1	14.5	39.6	8	.330	2
Kentucky.....	15	11.6	3	20.9	2	40.2	7	.031	12
Maryland.....	0	.0	14.5	.04	11	19.7	15	.000	14.5
New Mexico...	0	.0	14.5	.03	12.5	NA	NA	.000	14.5
Ohio.....	11	8.5	5	5.1	6	41.8	5.5	.093	6
Pennsylvania.	25	19.4	2	15.6	3	24.3	14	.070	7
Tennessee....	0	.0	14.5	1.3	9	34.4	11.5	.000	14.5
Utah.....	9	7.0	6	2.0	8	45.1	1	.198	3
Virginia.....	6	4.65	7	7.9	5	33.5	13	.033	11
Washington...	0	.0	14.5	.01	16	38.7	9	.000	14.5
West Virginia	40	31	1	31.8	1	35.0	10	.055	8
Wyoming.....	2	1.6	9.5	.1	14.5	43.9	2	.750	1

NA Not available.

It would seem reasonable to assume that coal volatility affects the fire-proneness of a coal seam and would be positively correlated with fire incidence. Table 2 also contains the average volatility found in each State and reported in Bureau of Mines Reports of Investigations. The correlation between coal volatility and fire incidence was found to be +0.16, which is not significant. Also, if the fire incident data are normalized to remove the effects of production exposure, the correlation between coal volatility and fire incidents per million tons mined for the top eight producing States is -0.55, which is not significant.

A chi-squared test indicated that the differences between States in terms of fires per million tons mined are statistically significant. However, the same analysis of the top five producing States indicated that the differences within that group are not significant and are due only to random variations. On fires-per-million-tons basis, Wyoming, Iowa, and Utah are the top three States.

Fires by Ignition Source

Table 3, which contains underground fires by ignition source and year, shows that the overwhelming ignition source is electrical. Table 3 also contains ignition source data grouped into three time periods: Early 1952 Mine Safety Law (1953-61), Late 1952 Mine Safety Law (1962-69), and 1969 Coal Mine Health and Safety Act (1970-77). There was an apparent downward trend in fire incidents over time for nearly all categories. A chi-squared test indicates that the trend was significant for electrical fires, open-flame and friction-induced fires, and fires caused by vandalism and spontaneous combustion, but the other differences were due to random variation.

A chi-squared test of the 1970-77 data indicates that the different ignition source totals are significantly different. With electrical fires removed, the differences between the remaining ignition sources are also significant.

Fires by Burning Substance

Table 4 contains underground fires by burning substance and year. The top three burning substances were coal, wiring insulation, and rubber. The same data are grouped into the three major time periods, and except for coal dust fires, there appears to be a downward trend over time for the top eight substances. These eight trends were found to be significant. A chi-squared test of the 1970-77 data on the top eight burning substances indicates that the different totals are significant and not due to chance variations.

TABLE 3. - Fires by ignition source

Ignition source	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67
Electrical	12	60	108	108	101	101
Friction	5	12	17	21	14	13
Spontaneous combustion	5	7	11	17	6	7
Explosives	0	4	2	3	6	1
Welding and/or cutting	0	3	4	1	8	4
Vandalism	2	2	1	4	2	0
Engine or clutch overheat	0	1	0	2	0	1
Open flame	0	1	3	1	0	2
Excess cable overheat	0	2	3	6	0	4
Adjacent or surface fire	1	2	0	3	1	2
Other	0	1	0	0	0	2
Unspecified or unknown	3	15	19	18	12	12
Total	28	110	168	184	150	149

	1968-69	1970-71	1972-73	1974-75	1976-77
Electrical	74	18	21	10	12
Friction	8	6	1	1	2
Spontaneous combustion	7	2	5	4	3
Explosives	0	1	0	0	0
Welding and/or cutting	3	2	6	2	1
Vandalism	0	1	0	0	0
Engine or clutch overheat	3	0	3	0	2
Open flame	1	1	0	1	0
Excess cable overheat	0	5	0	0	0
Adjacent or surface fire	0	0	0	0	0
Other	0	3	0	0	0
Unspecified or unknown	5	7	2	2	5
Total	101	46	38	20	25

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
Electrical	276	59.7	276	69.0	61	47.3	611	61.8	[1]139.49
Friction	50	10.8	35	8.75	10	7.75	95	9.6	[2]21.68
Spontaneous combustion	35	7.6	20	5.0	14	10.9	69	7.0	[1]7.31
Explosives	9	1.95	7	1.75	1	.8	17	1.7	[2]5.43
Welding and/or cutting	8	1.7	15	3.75	11	8.5	34	3.4	[2]1.51
Vandalism	9	1.5	2	.5	1	.8	12	1.7	[1]7.50
Engine or clutch overheat	3	.65	4	1	5	3.9	12	1.2	[2].31
Open flame	5	1.1	3	.75	2	1.6	10	1.0	[1]11.18
Excess cable overheat	11	2.4	4	1	5	3.9	20	2.0	[2]5.40
Adjacent or surface fire	5	1.1	3	.75	0	0	8	.8	[2]4.56
Other	1	.2	2	.5	3	2.3	6	.6	NAp
Unspecified or unknown	52	11.3	29	7.25	16	12.4	97	9.8	NAp
Total	462	100	400	100	129	100	991	100	-

NAp Not applicable.
[1]Statistically significant at the 0.01 level of confidence.
[2]Not statistically significant at the 0.05 level of condifence.

NOTE.--For 1970-77, χ^2 = 149.64 (statistically significant at the 0.01 level of confidence) with electrical fires, and χ^2 = 34.89 (statistically significant at the 0.01 level of confidence) without electrical fires.

TABLE 4. - Underground fires by burning substance

Burning substance[1]	1950-52	1953-55	1956-58	1959-61	1962-64	1967-67
Coal	22	52	70	85	55	67
Insulation	3	43	75	76	66	74
Coal dust	2	8	27	33	37	39
Oil	0	18	22	29	25	38
Grease	0	8	15	16	20	21
Belt or tire rubber	10	32	47	56	54	46
Timber	7	30	30	36	30	22
Hydraulic fluid	0	8	24	22	19	15
Cloth	0	2	3	3	4	1
Gas	0	1	2	2	2	1
Electrical equipment	0	1	0	0	3	3
Refuse	3	2	0	1	0	0
Methane	0	2	0	1	3	0
Explosives	0	0	0	0	2	1
Other	0	2	0	0	2	2
Unspecified or unknown	1	1	6	9	3	7
Total	48	210	321	369	324	340

	1968-69	1970-71	1972-73	1974-75	1976-77
Coal	30	17	17	11	12
Insulation	46	22	20	7	11
Coal dust	25	8	6	1	2
Oil	21	4	6	1	0
Grease	6	1	4	1	1
Belt or tire rubber	37	17	10	6	8
Timber	15	8	6	3	6
Hydraulic fluid	6	5	6	1	1
Cloth	1	1	2	0	20
Gas	1	4	3	2	0
Electrical equipment	4	0	0	2	3
Refuse	0	0	0	0	0
Methane	1	0	0	0	0
Explosives	0	1	0	0	0
Other	1	3	4	1	0
Unspecified or unknown	6	0	0	0	0
Total	200	92	83	38	44

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
Coal	207	23	152	17.6	57	22.2	416	20.6	[2]68.08
Insulation	194	21.6	186	21.5	60	23.3	440	21.8	[2]68.88
Coal dust	68	7.6	101	11.7	17	6.6	186	9.2	[2]59.30
Oil	69	7.7	84	9.7	11	4.3	164	8.1	[2]53.40
Grease	39	4.3	47	5.4	8	3.1	94	4.7	[2]26.51
Belt or tire rubber	135	15.0	137	15.9	41	16.0	313	15.5	[2]52.91
Timber	96	10.7	67	7.8	23	8.9	186	9.2	[2]43.22
Hydraulic fluid	54	6.0	40	4.6	13	5.0	107	5.3	[2]20.37
Cloth	8	.9	8	.9	4	1.6	20	1.0	[3]1.39
Gas	5	.6	4	.5	9	3.5	18	.9	[3]2.70
Electrical equipment	1	.1	10	1.2	5	1.9	16	.8	[3]4.83
Refuse	3	.3	0	0	0	0	3	.15	([3])
Methane	3	.3	4	.5	0	0	7	.35	([3])
Explosives	0	0	3	.3	1	.4	4	.2	NAp
Other	2	.2	5	.6	8	3.1	15	.7	NAp
Unspecified or unknown	16	1.8	16	1.8	0	0	32	1.6	NAp
Total	900	100	864	100	257	100	2,021	100	NAp

NAp Not applicable.

[1]In many fires, more than 1 substance was burning.

[2]Statistically significant at the 0.01 level of confidence.

[3]Not statistically significant at the 0.05 level of confidence.

NOTE.--For 1970-77, χ^2 = 364.77 (statistically significant at the 0.01 level of confidence).

Fires by Location

The locations of fires in a mine appear in table 5. The majority of fires occurred in the working areas of the mines where the powered equipment is located. The only exception is the gob area, where spontaneous combustion tends to occur. In fire location data grouped into the three major time periods, there is an apparent downward trend in fire incidents over time for all but the working face, which peaked during the second period. The apparent trends were found to be significant for the top six locations. A chi-squared test of the 1970-77 data indicates that the differences between fire incidence rates in the various locations are statistically significant. However, a test of the top six locations indicates that the differences between these fire frequencies are not statistically significant.

Fires by Equipment Involved

Table 6, which shows fires by equipment involved and year, indicates that the most fire-prone pieces of equipment are the conveyor belt, undercutter, shuttle car, locomotive, and loader. A chi-squared test found the differences between the top five fire incident totals to be significant. In the fire-incident totals for the three major periods of mine safety law, there appears to be a general downward trend in fire incidents for all types except acetylene equipment. These downward trends were found to be significant on all production equipment, but were not significant for support equipment.

During the 1970-77 period the most fire-prone pieces of mobile equipment were the conveyor belt, undercutter, locomotive, shuttle car, roof bolter, and continuous miner. Table 7 contains these pieces of equipment and the number of fires associated with each one over the 1970-77 period. Also included is an estimate of the average population of each equipment type during the 1970-75 time period. If all of these pieces of equipment were equally hazardous, then the expected number of fires for each piece would be in proportion to the relative populations. The locomotive, roof bolter, and continuous miner appear to have fire incident frequencies near their expected values. The shuttle car is below its expected value and is relatively safe on a per-unit basis. The conveyor belt and undercutter have more fires than expected and must be considered more hazardous than other equipment. A chi-squared test of the difference between actual and expected fire incidents found the difference to be significant.

Table 5. - Fires by location

Location	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67
Working face	0	8	35	46	44	42
Outby face	6	27	37	31	23	25
Haulageway	1	9	22	23	17	20
Main haulageway	2	9	7	7	26	4
Belt entry	8	20	24	25	15	21
Gob	5	6	18	14	5	11
Maintenance	0	2	2	0	1	1
Substation	1	2	3	1	1	3
Slope	1	3	1	2	3	3
Shaft	1	3	5	2	3	3
Other	0	3	1	4	4	0
Unspecified or unknown	3	19	14	26	8	15
Total	28	111	169	181	150	148
	1968-69	1970-71	1972-73	1974-75	1976-77	
Working face	26	10	5	2	3	
Outby face	21	11	7	4	1	
Haulageway	9	2	8	4	6	
Main haulageway	7	3	2	1	1	
Belt entry	14	10	3	1	4	
Gob	6	2	4	4	2	
Maintenance	1	2	1	0	4	
Substation	2	0	2	1	2	
Slope	2	2	1	0	0	
Shaft	4	1	4	0	0	
Other	0	0	1	0	0	
Unspecified or unknown	8	3	1	2	2	
Total	100	46	39	20	25	

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
Working face	89	19.3	112	28.1	20	15.5	221	22.4	[1]64.67
Outby face	95	20.6	69	17.3	23	17.8	187	18.9	[1]35.46
Haulageway	54	11.7	46	11.6	20	15.5	120	12.1	[1]13.02
Main haulageway	23	5.0	37	9.3	7	5.4	67	6.8	[1]21.07
Belt entry	69	15.0	50	12.6	18	14.0	137	13.9	[1]23.95
Gob	38	8.2	22	5.5	12	9.3	72	7.3	[1]10.97
Maintenance	4	.87	3	.75	7	5.4	14	1.4	[2]2.12
Substation	6	1.3	6	1.5	5	3.9	17	1.7	[2].10
Slope	6	1.3	8	2.0	3	2.3	17	1.7	[2]2.30
Shaft	10	2.2	10	2.5	5	3.9	25	2.5	[2]1.74
Other	8	1.7	4	1.0	1	.78	13	1.3	NAp
Unspecified or unknown	59	12.8	31	7.8	8	6.2	98	9.9	NAp
Total	461	100	398	100	129	100	988	100	NAp

NAp Not applicable.
[1]Statistically significant at the 0.01 level of confidence.
[2]Not statistically significant at the 0.05 level of confidence.

NOTE.--For 1970-77, χ^2 = 42.83 (statistically significant at the 0.01 level of confidence), all locations, and χ^2 = 10.73 (not statistically significant at the 0.01 level of confidence), first 6 locations.

TABLE 6. - Fires by equipment

Equipment	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67
Shuttle car	0	12	17	15	15	19
Continuous miner	0	3	4	3	9	5
Loader	0	4	12	14	7	7
Cutter	0	8	24	25	30	32
Belt	8	21	26	26	27	22
Pump or motor	0	1	2	2	4	4
Bolter	0	2	7	8	3	1
Locomotive	0	8	9	7	10	5
Compressor	0	2	1	3	0	1
Mine car	0	3	4	6	2	2
Electrical equipment	1	4	3	3	5	5
Acetylene equipment	0	0	0	0	0	1
Utility vehicle	1	0	0	2	3	0
Other	0	2	5	4	2	2
None	18	42	57	70	36	46
Unspecified or unknown	0	0	0	3	0	1
Total	28	112	171	191	153	152

	1968-69	1970-71	1972-73	1974-75	1976-77
Shuttle car	10	6	0	2	0
Continuous miner	4	3	2	0	0
Loader	2	1	0	0	0
Cutter	19	5	4	1	2
Belt	14	9	3	2	5
Pump or motor	2	1	1	0	1
Bolter	4	1	2	2	1
Locomotive	4	3	5	0	2
Compressor	2	0	3	1	1
Mine car	0	0	2	1	0
Electrical equipment	3	0	2	2	5
Acetylene equipment	1	3	1	1	0
Utility vehicle	1	0	0	0	1
Other	3	1	1	0	1
None	30	14	12	8	7
Unspecified or unknown	1	0	0	0	0
Total	101	47	38	20	26

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
Shuttle car	44	9.3	44	10.8	8	6.1	96	9.5	[1]25.12
Continuous miner	10	2.1	18	4.4	5	3.8	33	3.3	[2]8.47
Loader	30	6.3	16	3.9	1	.8	47	4.6	[1]23.27
Cutter	57	12.0	81	20.0	12	9.2	150	14.8	[1]49.85
Belt	73	15.4	63	15.5	19	14.5	155	15.3	[1]27.80
Pump or motor	5	1.0	10	2.5	3	2.3	18	1.8	[3]4.78
Bolter	17	3.6	8	2.0	6	4.6	31	3.1	[3]4.98
Locomotive	24	5.0	19	4.7	10	7.6	53	5.2	[3]4.37
Compressor	6	1.3	3	.7	5	3.8	14	1.4	[3].73
Mine car	13	2.7	4	1.0	3	2.3	20	2.0	[2]7.38
Electrical equipment	10	2.1	13	3.2	9	6.9	32	3.2	[3]1.09
Acetylene equipment	0	0	2	.5	5	3.8	7	.7	[3]5.94
Utility vehicle	2	.4	4	1.0	1	.8	7	.7	[3]2.18
Other	11	2.3	7	1.7	3	2.3	21	2.1	NAp
None	169	35.6	112	27.5	41	3.1	322	31.8	NAp
Unspecified or unknown	3	.6	2	.5	0	0	5	.5	NAp
Total	474	100	406	100	131	100	1,011	100	NAp

NAp Not applicable.
[1]Statistically significant at the 0.05 level of confidence.
[2]Statistically significant at the 0.01 level of confidence.
[3]Not statistically significant at the 0.05 level of confidence.

TABLE 7. - Fires by equipment involved, normalized for population, 1970-75

Equipment	Number of fires	Average equipment population[1]	E = 60 x equipment population / total population
Belt.....	19	3,906	12.24
Cutter.....	12	1,827	5.72
Locomotive.....	10	3,382	10.60
Shuttle car.....	8	5,786	18.13
Bolter.....	6	2,423	7.59
Continuous miner.....	5	1,827	5.72
Total.....	60	19,151	60.00

[1]BuMines Minerals Yearbook 1970-75.

NOTE.--For χ^2 = 16.75 (statistically significant at the 0.01 level of confidence).

The trailing cable through which mobile electrical equipment receives power (shuttle cars, continuous miners, undercutters, loading machines, and roof bolters) caused 71.4 pct of the fires on such equipment and 25.1 pct of all underground fires. Table 8 lists total fires and cable fires on shuttle cars, continuous miners, undercutters, loading machines, and roof bolters for the three major time periods. A decline in the proportion of fires caused by cable faults over time is indicated and can probably be attributed to the increased use of AC power. When the number of cable fires during 1970-77 is normalized for equipment populations, only undercutters show a statistically significant departure from the expected value, indicating undercutters are disproportionately susceptible to cable fires. Table 9 lists the four causes of cable fires for the three major time periods: (1) physical damage to the cable, which includes running over the cable, pinching the cable between machines or on the rib, roof falls onto the cable, and other cable damage; (2) faulty splices in the cable; (3) cable faults, which include internal shorts and chassis shorts; and (4) reel faults, which include faults in the cable when on the reel and heating of cable on the reel. A chi-squared test indicates the causes of cable fires to be significant for each equipment category and for all equipment.

Fires by Detection

Table 10 lists the means of fire detection and shows that the top three fire detectors were the machine operator, supervisor, and fire boss. The same downward trend over time is evident in the three major time periods. In the 1970-77 data, the most frequent fire detectors were the machine operators, fire boss, supervisor, mechanic or electrician, and repair crew. Differences in fire detection frequency between these five groups are significant. If "other" and unspecified" detections are removed and machine operators are combined with locomotive operators, then 36 pct of all reportable fires are detected by the operator attending the equipment, and 64 pct of the fires are detected by an individual patrolling the mine or investigating an unusual occurrence such as equipment failure or smoke.

TABLE 8. - Number of cable fires, three major time periods

Equipment	1953-61			1962-69		
	Total fires	Cable	Pct cable	Total fires	Cable	Pct cable
Shuttle car	44	38	86.3	44	39	88.6
Continuous miner	10	9	90.0	18	8	44.4
Cutter	57	40	70.2	81	48	59.3
Loader	30	22	73.3	16	13	81.3
Bolter	17	15	88.2	8	6	75.0
All equipment	158	124	78.5	167	114	68.2
	1970-77			Total fires		
	Total fires	Cable	Pct cable	Total fires	Cable	Pct cable
Shuttle car	8	7	87.5	96	84	87.5
Continuous miner	5	1	20.0	33	18	54.5
Cutter	12	8	66.7	150	96	64.0
Loader	1	0	.0	47	35	74.4
Bolter	6	1	16.6	31	22	70.9
All equipment	32	17	53.1	357	255	71.4

	Average equipment population, 1970-75	[1]$E = 17 \times \frac{\text{equipment population}}{\text{total population}}$	χ^2 cable fires, 1970-77
Shuttle car	5,786	8.29	[2]0.20
Continuous miner	1,827	2.62	[2]1.00
Cutter	1,827	2.62	[3]11.05
Loader	NA	NA	NA
Bolter	2,423	3.47	[2]1.76
All equipment	11,863		

NA Not available.

[1]Expected number of cable-related fires 1970-77.

[2]Not statistically significant at the 0.05 confidence level.

[3]Statistically significant at the 0.01 confidence level.

TABLE 9. - Causes of cable fires, three major time periods

Equipment	1953-61								1962-69							
	Physical damage		Faulty splice		Cable fault		Reel fault		Physical damage		Faulty splice		Cable fault		Reel fault	
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct
Shuttle car.....	9	24	14	63	9	24	6	16	11	28	10	26	9	23	9	23
Continuous miner	3	33	0	0	6	67	0	0	2	25	1	12	4	50	1	12
Cutter.....	5	13	13	33	16	40	6	15	8	17	23	48	5	10	12	25
Loader.....	7	32	6	27	6	27	3	13	6	46	4	31	2	15	1	8
Bolter.....	9	60	2	13	3	20	1	8	2	33	3	50	1	17	0	0
Total or average.....	33	27	35	28	40	32	16	13	29	35	41	36	21	18	23	20

Equipment	1970-77								Total								χ^2 (1970-77)
	Physical damage		Faulty splice		Cable fault		Reel fault		Physical damage		Faulty splice		Cable fault		Reel fault		
	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	No.	Pct	
Shuttle car.....	1	14	2	29	3	43	1	14	21	25	26	31	21	25	16	19	[1]12.38
Continuous miner	1	100	0	0	0	0	0	0	6	33	1	6	10	56	1	6	[2]12.26
Cutter.....	0	0	4	50	0	0	4	50	13	14	40	42	21	22	22	23	[2]16.26
Loader.....	0	0	0	0	0	0	0	0	13	37	10	29	8	23	4	11	[1]4.88
Bolter.....	0	0	0	0	1	100	0	0	11	50	5	23	5	23	1	5	[1]9.28
Total or average.....	2	12	6	35	3	25	5	29	64	25	82	32	65	25	44	17	[2]11.36

[1]Statistically significant at the 0.05 level of confidence.
[2]Statistically significant at the 0.01 level of confidence.

TABLE 10. - Fires by detection

Detection	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67
Machine operator	1	15	51	49	52	54
Locomotive operator	1	6	9	8	9	11
Fire boss	2	13	18	15	16	2
Supervisor	2	16	19	30	20	17
Beltworker	1	4	4	1	1	3
Facecrew	3	15	18	18	10	2
Pumpworker	2	2	2	3	1	2
Mechanic/Electrician	3	3	9	9	6	11
Superintendent/Owner	0	3	3	3	3	5
Repair crew	4	11	12	7	4	9
Surface employee	2	1	0	2	1	6
Government inspector	0	0	0	2	0	0
Local resident	0	1	0	1	1	1
Laborer	1	0	2	1	4	1
Supply crew	0	2	4	3	0	1
Other	1	1	3	2	3	2
Unspecified or unknown	5	16	14	27	20	20
Total	28	109	168	181	151	149

Detection	1968-69	1970-71	1972-73	1974-75	1976-77
Machine operator	32	13	11	3	5
Locomotive operator	6	3	5	0	1
Fire boss	5	4	6	4	7
Supervisor	15	7	4	3	2
Beltworker	2	1	1	0	1
Facecrew	2	1	0	3	0
Pumpworker	2	0	1	0	0
Mechanic/Electrician	5	7	2	2	2
Superintendent/Owner	2	1	0	0	1
Repair crew	5	4	4	2	2
Surface employee	3	0	0	1	0
Government inspector	2	0	0	0	0
Local resident	1	0	0	0	0
Laborer	0	0	0	0	0
Supply crew	0	0	0	0	0
Other	4	3	2	1	0
Unspecified or unknown	14	3	3	1	4
Total	100	46	38	20	25

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
Machine operator	115	25.1	138	34.7	32	24.4	285	28.9	[1]63.94
Locomotive operator	23	5.0	26	6.5	9	6.9	58	5.9	[2]8.12
Fire boss	46	10.0	23	5.8	21	16.0	90	9.1	[2]8.98
Supervisor	65	14.2	52	13.1	16	12.2	133	13.5	[1]24.79
Beltworker	9	2.0	6	1.5	3	2.3	18	1.8	[3]2.31
Facecrew	51	11.1	14	3.5	4	3.1	69	7.0	[1]45.31
Pumpworker	7	1.5	5	1.3	1	.76	13	1.3	[3]4.11
Mechanic/Electrician	21	4.6	22	5.5	13	9.9	56	5.7	[3]2.31
Superintendent/Owner	9	2.0	10	2.5	2	1.5	21	2.1	[3]5.19
Repair crew	30	6.6	18	4.5	12	9.2	60	6.1	[2]6.04
Surface employee	3	.66	10	2.5	1	.76	14	1.4	[1]10.33
Government inspector	2	.44	2	.50	0	.0	4	.41	([3])
Local resident	2	.44	3	.75	0	.0	5	.51	([3])
Laborer	3	.66	5	1.3	0	.0	8	.81	([3])
Supply crew	9	2.0	1	.25	0	.0	10	1.0	[1]12.8
Other	6	1.3	9	2.3	6	4.6	21	2.1	NAp
Unspecified or unknown	57	12.4	54	13.6	11	8.4	122	12.4	NAp
Total	458	100	398	100	131	100	987	100	NAp

NAp Not applicable.
[1]Statistically significant at the 0.01 level of confidence.
[2]Statistically significant at the 0.05 level of confidence.
[3]Not statistically significant at the 0.05 level of confidence.
NOTE.--For 1970-77, χ^2 = 14.9 (statistically significant at the 0.01 level of condifence) for the first 5 means of detection.

Figure 2 contains the percentage of fires detected during each period of the day for the 1950-77 data. The different frequencies between time periods were found to be significant. Most fires were discovered during preshift inspection or early first shift. This may be because many mines run only one or two shifts; if fires start at random times, they are less likely to be discovered during the second or third shift when fewer employees are present and will probably be discovered by the returning first shift. Another possibility is that more electrical equipment is operated during the first and second shifts, thereby generating more fires. The data in figure 2 are probably a result of both effects.

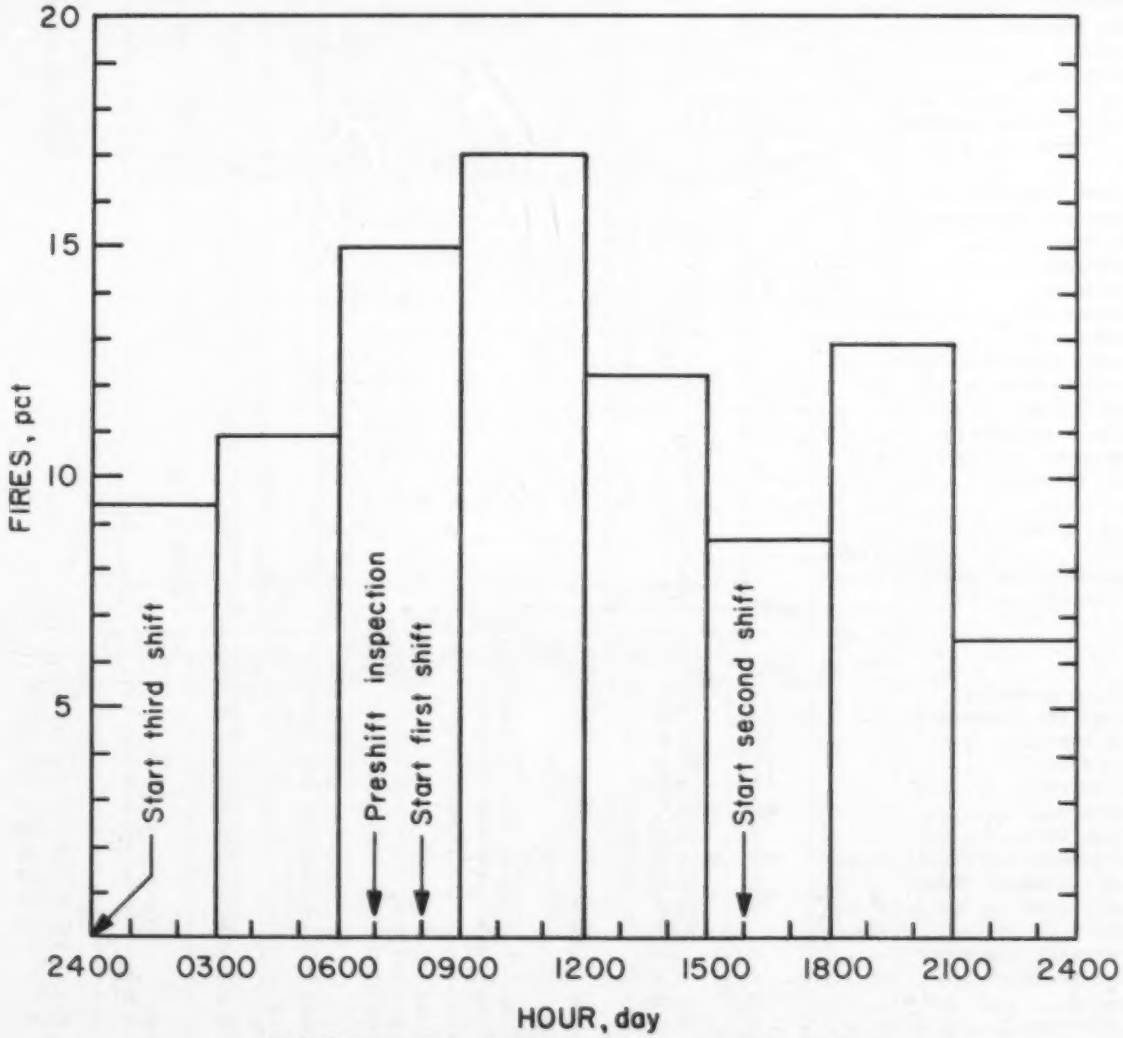

FIGURE 2. - Fire detection frequency by time of day.

Fires by Duration

Table 11, which lists the duration of fires, shows that most fires lasted from 1 to 4 hours. Many of the fires lasted less than 30 minutes and were nonreportable based on duration, but some of these were reportable due to an injury or were informally reported. The same downward trend in fires over time for the three major time periods is apparent for all but major fires (those lasting over 24 hours) which remained fairly stable over the years.

TABLE 11. - Fires by duration

Duration	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
0 to 15 min.....	38	8.3	52	13.0	28	21.7	118	12.0	[1]8.37
15 to 30 min.....	31	6.8	40	10.0	12	9.3	83	8.4	[1]14.82
30 min to 1 hr.....	53	11.6	36	9.0	11	8.5	100	10.1	[1]22.31
1 to 4 hr.....	87	19.0	91	22.0	28	21.7	206	20.9	[1]33.58
4 to 24 hr.....	60	13.1	56	14.0	15	11.6	131	13.3	[1]25.51
Over 24 hr.....	35	7.6	23	5.8	28	21.7	86	8.7	[2]1.28
Unspecified or unknown	154	33.6	101	25.3	7	5.4	262	26.6	NAp
Total.....	458	100	399	100	129	100	986	100	NAp

NAp Not applicable.
[1]Statistically significant at the 0.05 level of confidence.
[2]Not statistically significant at the 0.05 level of confidence.

An analysis was conducted on the 1970-77 data to determine whether fire duration is affected by coal volatility. Average volatility of coal for each fire duration was calculated and ranked. The rank order correlation between coal volatility and fire duration was found to be +0.37, which is not significant. Possibly mines in volatile coal regions compensate with increased fire safety equipment and procedures.

Fires by Injury

Fire injuries appear in table 12. Because of the small sample size, the downward trend over time is significant for only the two- to five-injury category.

A cross tabulation of 1970-77 injury fires by ignition source indicated that six were electrical in origin, one was due to welding, one due to ignition, and two due to unknown causes. These differences are significant. Injury fires by equipment indicated three welding equipment fires and one each for the roof bolter, locomotive, pump and motor, shuttle car, compressor, and batteries. These differences are not significant. Injury fires by location indicated four fires by the face, two in the haulageway, and one each at the working face, maintenance area, and shaft. Because of the small sample size, these differences are not significant.

TABLE 12. - Fires by number of injuries

Injuries	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67
0.....	26	97	152	169	138	138
1.....	2	6	7	6	4	5
2 to 5.....	0	4	8	5	8	5
5 to 10.....	0	2	1	1	0	0
Over 10.....	0	0	0	0	0	1
Total....	28	109	168	181	150	149
	1968-69	1970-71	1972-73	1974-75	1976-77	
0.....	91	42	36	17	24	
1.....	7	3	2	1	0	
2 to 5.....	2	1	0	0	0	
5 to 10.....	0	0	0	2	1	
Over 10.....	0	0	0	0	0	
Total....	100	46	38	20	25	

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
0.....	418	91.3	367	92.0	119	92.2	904	91.7	NAp
1.....	19	4.1	16	4.0	6	4.7	41	4.2	[1]5.71
2 to 5.....	17	3.7	15	3.8	1	.8	33	3.3	[2]25.52
5 to 10.....	4	.9	0	.0	3	2.3	7	.7	([1])
Over 10.....	0	.0	1	.3	0	.0	1	.1	([1])
Total....	458	100	399	100	129	100	986	100	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.
[2]Statistically significant at the 0.01 level of confidence.

Fires by Number of Deaths

In table 13, which lists fires by number of deaths, the data are grouped into three major time periods. Owing to the small sample size, no trends are significant. All five fatal fires in the 1970-77 period were electrical in origin. Four of the fires involved equipment: one fire each on a loader, undercutter, continuous miner, and roof bolter. Three of the fires occurred outby the face, and the other two were at the working face.

TABLE 13. - Fires by number of deaths

Deaths	1950-52	1953-55	1956-58	1959-61	1962-64	1967-67
0	27	109	163	176	147	145
1	0	0	5	3	2	2
2 to 5	1	0	0	1	1	1
5 to 10	0	0	0	0	0	1
Over 10	0	0	0	1	0	0
Total	28	109	168	181	150	149

	1968-69	1970-71	1972-73	1974-75	1976-77
0	98	44	35	19	25
1	1	1	1	1	0
2 to 5	1	1	0	0	0
5 to 10	0	0	1	0	0
Over 10	0	0	1	0	0
Total	100	46	38	20	25

	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
0	448	97.8	390	97.7	123	95.3	961	97.5	NAp
1	8	1.7	5	1.3	3	2.3	16	1.6	[1]1.75
2 to 5	1	.2	3	.8	1	.7	5	5.1	([1])
5 to 10	0	.0	1	.3	1	.7	2	2.0	([1])
Over 10	1	.2	0	.0	1	.7	2	2.0	([1])
Total	458	100	399	100	129	100	986	100	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.

Fires by Successful Extinguishing Agent or Method

Table 14 lists water, rock dust, dry chemical, and sealing as the top four extinguishing agents used in reportable fires from 1970 to 1977. The same general downward trend in the data grouped by major time periods is apparent in agreement with the overall fire frequency. However, the relative percentages within time periods show no strong trends. Differences in frequencies among extinguishing agents were found to be significant.

TABLE 14. - Fires by successful extinguishing agent or method

Successful extinguishing agent or method	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67
Water	12	57	82	101	89	85
Rock dust	9	31	60	63	58	54
Dry chemical	2	21	45	28	40	31
Carbon dioxide	0	2	6	18	13	19
Sealing	10	27	35	29	16	23
Power removed	0	2	7	9	9	1
Burned out	0	2	1	4	4	4
Foam	0	0	0	1	0	4
Soda acid	0	1	0	3	2	0
Load-out	3	0	0	1	1	0
Other	0	2	2	4	2	3
Unspecified or unknown	2	6	12	2	2	4
Total	38	151	250	263	236	228

	1968-69	1970-71	1972-73	1974-75	1976-77
Water	65	25	19	11	16
Rock dust	34	15	4	4	1
Dry chemical	31	14	14	6	6
Carbon dioxide	6	4	1	2	0
Sealing	12	5	9	5	4
Power removed	5	1	0	0	0
Burned out	4	1	1	0	1
Foam	2	0	0	0	0
Soda acid	0	0	0	0	0
Load-out	0	0	0	0	0
Other	1	1	0	1	0
Unspecified or unknown	1	2	0	2	1
Total	161	68	48	31	29

	Major time periods							
	1953-61		1962-69		1970-77		1953-77	
	Total	Pct	Total	Pct	Total	Pct	Total	Pct
Water	240	36.1	239	38.2	71	40.3	550	37.5
Rock dust	154	23.2	146	23.4	24	13.6	324	22.1
Dry chemical	94	14.2	102	16.3	40	22.7	236	16.1
Carbon dioxide	26	3.9	38	6.1	7	4.0	71	4.8
Sealing	91	13.7	51	8.2	23	13.1	165	11.3
Power removed	18	2.7	15	2.4	1	.6	34	2.3
Burned out	7	1.1	12	1.9	3	1.7	22	1.5
Foam	1	.15	6	1.0	0	0	7	.5
Soda acid	4	.6	2	.3	0	0	6	.4
Load-out	1	.15	1	.2	0	0	2	.1
Other	8	1.2	6	.1	2	1.1	16	1.1
Unspecified or unknown	20	3.0	7	1.1	5	2.8	32	2.2
Total	664	100	625	100	176	100	1,465	100

NOTE.--For 1970-77, χ^2 = 38.10 (statistically significant at the 0.01 level of confidence).

Surface Fires at Surface and Underground Mines

Time Trends

The first analysis was made to determine time-trend effects on the number of fires in each year. Table 15 contains fire incidents by year for surface fires. As shown in figure 3, there is a definite trend toward a high number of fires in 1962, followed by a decrease and stabilization around 1968. When this curve is compared with coal production, it is apparent that the rise in fire incidence coincides with production increases. The downward trend is possibly due to increased safety measures. A rank order correlation between fire incidence and data during the upward (1954-63), downward (1964-70), and stable (1970-77) part of the curve yielded Spearman's rho correlation coefficients of 0.59, -0.64, and 0.41, all of which are not

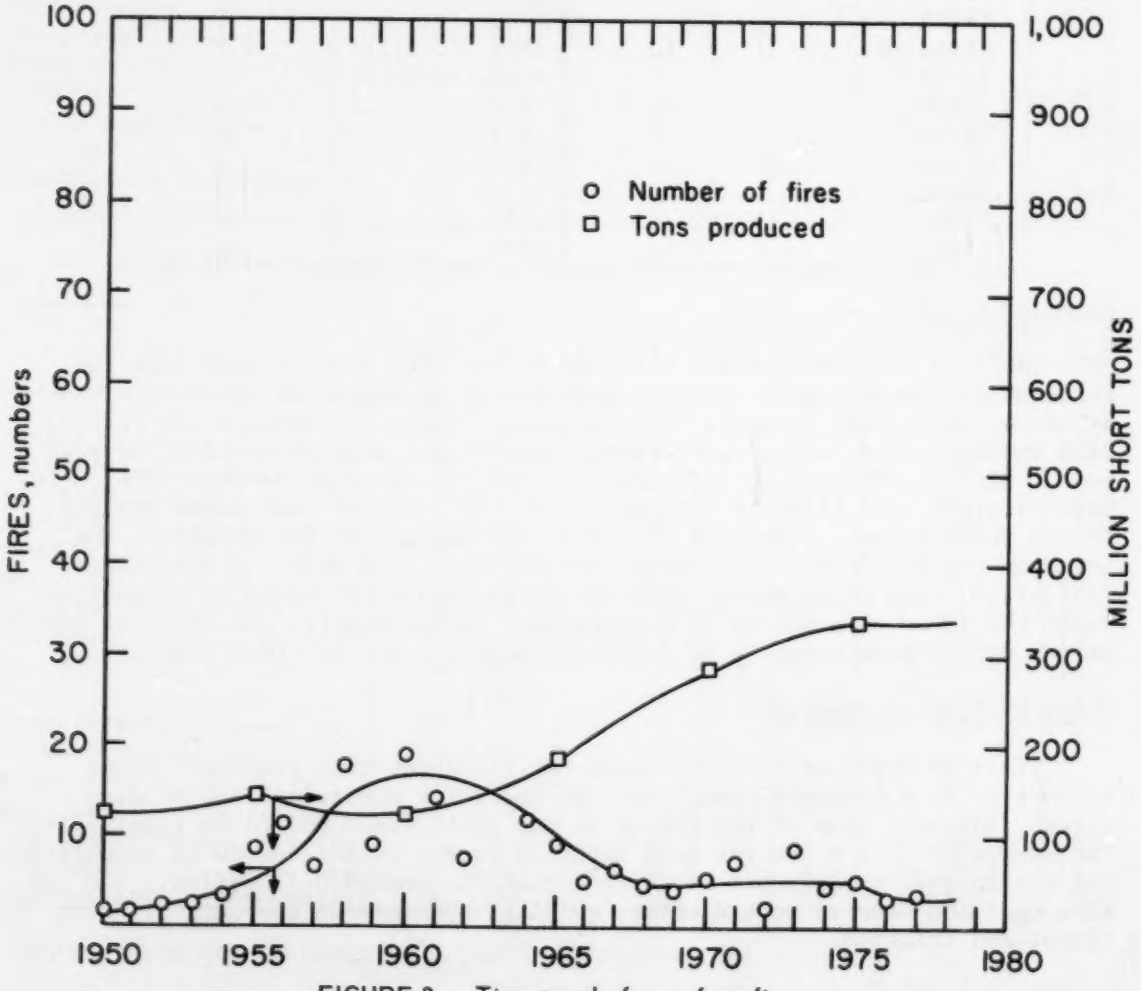

FIGURE 3. - Time trends for surface fires.

significant. A chi-squared test of the relative fire incidence of these three periods found the frequencies to be significantly different.

Because fire data from 1970 to 1977 are most pertinent to current considerations, the analysis below concentrates on that time period.

TABLE 15. - Surface fire incidents by year

Year	Surface fire incidents	Year	Surface fire incidents
1950.....	1	1964.....	11
1951.....	1	1965.....	8
1952.....	2	1966.....	4
1953.....	2	1967.....	7
1954.....	3	1968.....	5
1955.....	8	1969.....	4
1956.....	10	1970.....	5
1957.....	5	1971.....	7
1958.....	15	1972.....	2
1959.....	9	1973.....	8
1960.....	16	1974.....	5
1961.....	13	1975.....	5
1962.....	6	1976.....	4
1963.....	18	1977.....	4

Fires by State

Table 16 contains surface fires by State, with data grouped into the three major time periods. The top four States in number of fires were Pennsylvania, Ohio, West Virginia, and Colorado. Table 17 contains the 1970-77 fire incident data, along with average yearly coal mine production for each year. During 1970 through 1977, the top four States were Pennsylvania, Ohio, West Virginia, and Illinois. Fires per million tons of coal mines appears in the third column. When the fire data are normalized for exposure, the top four States are Iowa, Colorado, Pennsylvania, and Ohio. A chi-squared test of the fire rates versus expected rates (table 18) based on production found the difference not to be significant. Consequently, the top four States do not differ significantly in terms of fires per million tons mined.

Fires by Ignition Source

Table 19 contains fire incidents for the three time periods. There appears to be a downward trend over the years for electrical and welding fires. However, none of the trends in the table was found to be significant. The different fire rates for each ignition source were found to be significant for the 1953-77 period, but not significant for the 1970-77 period. The top five ignition sources were electri, welding, spontaneous combustion, open flame, and friction.

TABLE 16. - Surface Fires by State

State	Major time periods			1953-77	
	1953-61	1962-69	1970-77	Total	Pct
Alabama	0	0	1	1	0.5
Alaska	1	0	0	1	.5
Colorado	9	2	2	13	7.1
Illinois	4	1	3	8	4.3
Indiana	3	1	2	6	3.3
Iowa	0	0	1	1	.5
Kentucky	1	5	2	8	4.3
Maryland	1	0	0	1	.5
Missouri	2	0	0	2	1.1
New Mexico	1	1	0	2	1.1
Ohio	8	8	7	23	12.5
Pennsylvania	35	31	13	79	42.9
Tennessee	2	0	0	2	1.1
Utah	4	3	0	7	3.8
Virginia	0	3	1	4	2.2
West Virginia	9	7	7	23	12.5
Wyoming	0	1	0	1	.5
Unspecified or unknown	1	0	1	2	1.1
Total	81	63	40	184	100

TABLE 17. - Surface fires per million tons production, 1970-77

State	Fires		Average production		Fire rate	
	Total	Rank	Million tons[1]	Rank	Per million tons	Rank
Alabama	1	9	19.9	8	0.05	7.5
Alaska	0	15	.7	16.5	.00	14
Colorado	2	6	6.6	12	.30	2
Illinois	3	4	59.8	4	.05	7.5
Indiana	2	6	23.9	7	.08	5
Iowa	1	9	.7	16.5	1.43	1
Kentucky	2	6	130.2	1	.02	10
Maryland	0	14	2.0	15	.00	14
Missouri	0	14	4.8	14	.00	14
New Mexico	0	14	8.7	10	.00	14
Ohio	7	2.5	48	5	.15	4
Pennsylvania	13	1	77.8	3	.17	3
Tennessee	0	14	8.6	11	.00	14
Utah	0	14	5.7	13	.00	14
Virginia	1	9	33.4	6	.03	9
West virginia	7	2.5	114.3	2	.06	6
Wyoming	0	14	15.6	9	.00	14
Unspecified or unknown	1	NA	NA	NA	NA	NA

NA Not available.

[1]BuMines Minerals Yearbook 1971, 1973, 1975; Coal Age.

TABLE 18. - Surface fire rate versus expected rate

State	Fires	Average production, million tons	Actual fire rate	E = 23 x State production / total production
Iowa	1	0.7	1.43	0.12
Colorado	2	6.6	.30	1.14
Pennsylvania	13	77.8	.17	13.45
Ohio	7	48.0	.15	8.29
Total	23	133.1	0.17	23.00

NOTE.--χ^2 = 7.31 (not statistically significant at the 0.05 level of confidence).

TABLE 19. - Surface fires by ignition source

Ignition source	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
Electrical	14	10	4	28	15.1	[1]4.39
Friction	2	1	5	8	4.3	[1]3.55
Spontaneous combustion	3	2	7	12	6.5	[1]3.88
Hot slag or sparks from welding or cutting	15	9	4	28	15.1	[1] 5.15
Vandalism	0	2	2	4	2.2	([1])
Engine or clutch overheat	1	1	1	3	1.6	([1])
Open flame	3	7	1	11	5.9	[1]5.48
Stove or heater overheat	2	4	0	6	3.2	([1])
Lightning	3	1	1	5	2.7	([1])
Leaking flammable fluid	0	0	4	4	2.2	([1])
Other	1	2	2	5	2.7	NAp
Unspecified or unknown	37	24	10	71	38.4	NAp
Total	81	63	41	185	100	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.
NOTE.--For 1953-77, χ^2 = 22.02 (statistically significant at the 0.01 level of confidence) for the top 5 ignition sources. For 1970-77, χ^2 = 1.42 (not statistically significant at the 0.05 level of confidence) for the top 5 ignition sources.

Fires by Burning Substance

Table 20 contains surface fires by burning substance. Because of the small size, none of the trends over time is significant. The differences in fire rates for the various burning substances were found to be significant for the 1953-77 period, but not for the 1970-77 period. The top five burning substances were timber and wood, coal, rubber, wiring insulation, and oil.

TABLE 20. - Surface fires by burning substance

Burning substance[1]	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
Timber and wood	57	34	14	105	29.7	[2]21.19
Coal	20	16	12	48	13.6	[2]1.19
Insulation	10	9	12	31	8.8	[2].64
Rubber	9	14	11	34	9.6	[2]1.75
Oil	12	12	7	31	8.8	[2]1.36
Grease	5	2	3	10	2.8	[2]1.01
Cloth	2	6	6	14	4.0	[2]2.87
Dust	4	8	8	20	5.7	[2]2.22
Explosives	2	3	2	7	2.0	([2])
Refuse	1	0	0	1	.3	([2])
Gasoline	2	1	1	4	1.1	([2])
Diesel fuel	1	2	2	5	1.4	([2])
Gas	1	3	3	7	2.0	([2])
Kerosine	0	1	0	1	.3	([2])
Hydraulic fluid	1	3	4	8	2.3	[2]2.11
Other	1	1	5	7	2.0	NAp
Unspecified or unknown	13	6	1	20	5.7	NAp
Total	141	121	91	353	100	NAp

NAp Not applicable.
[1]Some fires involve more than one burning substance.
[2]Not statistically significant at the 0.05 level of confidence.

NOTE.--For 1953-61, χ^2 = 80.46 (statistically significant at the 0.01 level of confidence) for the top 5 substances. For 1970-77, χ^2 = 1.68 (not statistically significant at the 0.05 level of confidence) for the top 5 substances.

Fires by Location

Th locations of surface fires at a mine appear in table 21. There is an apparent trend downward over time in terms of fire frequency for many of the locations. These trends are significant for the tipple, crusher and/or breaker, and substation. Fire rates for the top five locations were found to be significantly different in the 1953-77 data. The top five fire locations were the tipple, crusher and/or breaker, cleaning plant, storage building, and miscellaneous surface buildings.

Fires by Equipment Involved

Table 22 contains surface fires by equipment involved. The apparent downward trend over time is significant for the tipple and crusher and/or breaker. Fire rates for the top five equipment categories were not found to be significantly different in either the 1953-77 data or 1970-77 data. The top five equipment categories were crusher and/or breaker, tipple, cleaning plant, belt, and electrical equipment.

TABLE 21. - Surface fires by location

Location	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
Cleaning (preparation) plant.....	12	9	4	25	13.0	[1]3.90
Tipple.....	20	9	2	31	16.1	[2]13.41
Belt.....	3	5	1	9	4.7	([1])
Hoist room.....	6	5	2	13	6.7	([1])
Crusher and/or breaker.....	15	11	3	29	15.0	[3]6.56
Fanhouse.....	4	2	1	7	3.6	([1])
Substation.....	7	3	0	10	5.2	[3]6.42
Silo and/or raw coal storage.....	1	2	5	8	4.1	[1]3.68
Storage building.....	7	5	2	14	7.3	[1]2.20
Shop and/or garage.....	3	3	1	7	3.6	([1])
Coalbed and/or pit.....	0	3	0	3	1.6	([1])
Miscellaneous surface building.....	6	3	5	14	7.3	[1].73
Road.....	0	1	1	2	1.0	([1])
Mining equipment.....	0	1	3	4	2.0	([1])
Other.....	1	2	2	5	2.6	NAp
Unspecified or unknown.....	1	3	8	12	6.2	NAp
Total.....	86	67	40	193	100	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.
[2]Statistically significant at the 0.01 level of confidence.
[3]Statistically significant at the 0.05 level of confidence.

NOTE.--For 1953-77, χ^2 = 11.74 (statistically significant at the 0.01 level of confidence) for the top 5 locations. For 1970-77, χ^2 = 1.00 (not statistically significant at the 0.05 level of confidence for the top 5 locations.

TABLE 22. - Surface fires by equipment involved

Equipment	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
Cleaning (preparation) plant.....	12	8	2	22	9.7	[1]5.84
Tipple.....	21	9	2	32	14.2	[2]14.58
Belt.....	7	10	4	21	9.3	[1]2.74
Crusher and/or breaker.....	17	14	2	33	14.6	[3]10.27
Electrical equipment.....	10	5	2	17	7.5	[1]4.67
Shop.....	3	4	2	9	4.0	([1])
Hoist room.....	5	5	3	13	5.8	([1])
Fanhouse.....	4	2	0	6	2.7	([1])
Storage building and contents.....	5	0	3	8	3.5	[1]4.20
Miscellaneous surface building.....	4	1	4	9	4.0	[1]1.84
Weighhouse.....	4	1	0	5	2.2	([1])
Warehouse.....	1	6	0	7	3.1	([1])
Office.....	3	4	1	8	3.5	([1])
Dragline.....	0	0	2	2	.9	([1])
Front-end loader.....	0	0	4	4	1.8	([1])
Other.....	4	5	10	19	8.4	NAp
None.....	2	6	3	11	4.9	NAp
Total.....	102	80	44	226	100.0	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.
[2]Statistically significant at the 0.01 level of confidence.
[3]Statistically significant at the 0.05 level of confidence.

NOTE.--For 1953-77, χ^2 = 8.08 (not statistically significant at the 0.05 level of confidence) for the top 5 equipment sources. For 1970-77, χ^2 = 0.33 (not statistically significant ath the 0.05 level of confidence) for the top 5 equipment sources.

Fires by Detection

Table 23 contains surface fires by means of detection. The only significant trends over time are a downward trend for the fires detected by supervisors and an upward trend for the fires detected by machine operators. Fire rates for the top means of fire detection are not sifnificantly different for either time period. Local residents, miscellaneous employees, supervisors, repair crew, and guards were the top five detectors of fires.

TABLE 23. - Surface fires by detection

Detection	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
Guard	7	3	2	12	6.5	[1]2.72
Supervisor	9	2	2	13	7.0	[2]6.23
Local resident	13	6	3	22	11.8	[1]5.73
Passerby	7	3	1	11	5.9	[1]4.21
Machine operator	0	2	6	8	4.3	[2]7.63
Mechanic or electrician	0	6	0	6	3.2	([1])
Repair crew	5	5	3	13	7.0	[1].51
Hoist engineer	0	2	2	4	2.1	([1])
Nonmine workers	3	0	0	3	1.6	([1])
Miscellaneous employee	9	4	8	21	11.3	([1])
Alarm	1	0	1	2	1.1	([1])
Owner or lessee	2	1	1	4	2.1	([1])
Other	1	1	0	2	1.1	NAp
Unspecified	24	30	11	65	35.0	NAp
Total	81	65	40	186	100.0	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.
[2]Statistically significant at the 0.05 level of confidence.

NOTE.--For 1953-77, $\chi^2 = 5.85$ (not statistically significant at the 0.05 level of confidence) for the top 5 detectors. For 1970-77, $\chi^2 = 3.60$ (not statistically significant at the 0.05 level of confidence) for the top 4 detectors.

Fires by Duration

Fires by duration appear in table 24. The most frequent fire duration category is 1 to 4 hours. None of the trends apparent in the table was found to be significant.

Fires by Injury

Table 25 contains surface fires by number of injuries. No significant trends are apparent owing to the small sample size. A cross tabulation of injury fires by ignition source indicated that injuries resulted from eight welding fires, four electrical fires, two each for open flame and flammable liquid fires, one each for spontaneous combustion and friction fires, and three from fires with unknown causes.

TABLE 24. - Surface fires by duration

Duration	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
0 to 15 min	0	2	2	4	2.2	(1)
15 to 30 min	5	3	4	12	6.5	(1)
30 min to 1 hr	1	5	3	9	4.9	[1]3.11
1 to 4 hr	15	12	8	35	19.0	[1]1.43
4 to 24 hr	8	5	4	17	9.2	[1].99
Over 24 hr	2	0	1	3	1.6	(1)
Unspecified or unknown	50	36	18	104	56.5	NAp
Total	81	63	40	184	100.0	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.

TABLE 25. - Surface fires by injuries

Injuries	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
0	75	54	34	163	88.6	(1)
1	3	4	3	10	5.4	(1)
2 to 5	3	5	3	11	6.0	(1)
5 to 10	0	0	0	0	NAp	(1)
Over 10	0	0	0	0	NAp	(1)
Total	81	63	40	184	100.0	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.

Fires by Number of Deaths

Table 26 contains surface fires by number of deaths. No significant trends are apparent due to small sample size. A cross tabulation of fatal fires by ignition source indicated that they were a result of two welding fires, two open flame fires, one flammable fluid fire, one heater fire, and one fire with unknown cause.

TABLE 26. - Surface fires by number of deaths

Deaths	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
0	80	61	36	177	96.2	NAp
1	1	2	4	7	3.8	(1)
2 to 5	0	0	0	0	0	NAp
5 to 10	0	0	0	0	0	NAp
Over 10	0	0	0	0	0	NAp
Total	81	63	40	184	100.0	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.

Fires by Successful Extinguishing Agent or Method

Table 27 contains surface fires by successful extinguishing agent. None of the apparent trends are significant. The top three extinguishing agents for the 1953-77 data were water, dry chemical, and rock dust. The top two extinguishing agents for the 1970-77 data were water and dry chemical. The success frequencies for the specified agents are significantly different.

TABLE 27. - Surface fires by successful extinguishing agent

Successful extinguishing agent	Major time periods			1953-77		
	1953-61	1962-69	1970-77	Total	Pct	χ^2
Water	45	41	23	109	54.0	[1]5.97
Dry chemical	4	5	6	15	7.4	([1])
Rock dust	2	5	2	9	4.5	([1])
Excavation	3	1	2	6	3.0	([1])
Sealing	2	1	0	3	1.5	([1])
Smothering by hand	0	2	2	4	2.0	([1])
Foam	1	2	0	3	1.5	([1])
None	19	3	6	28	13.9	NAp
Unspecified	11	11	3	25	12.4	NAp
Total	87	71	44	202	100.0	NAp

NAp Not applicable.
[1]Not statistically significant at the 0.05 level of confidence.

NOTE.--For 1953-77, χ^2 = 141.89 (statistically significant at the 0.01 level of confidence) for the top 3 extinguishing agents. For 1970-77, χ^2 = 9.97 (statistically significant at the 0.01 level of confidence) for the top 2 extinguishing agents.

Nonreportable Fires

Nonreportable data were analyzed in two sets. Results are discussed under the headings of underground fires and surface fires.

Underground Fires

Fires by Ignition Source

Ignition sources of nonreportable fires appear in table 28. The majority of these fires were electrical in origin, primarily wiring shorts, battery chargers, and cable overheating. The second highest ignition source was friction, primarily from conveyor belts. The totals for electrical and friction fires are not significantly different.

TABLE 28. - Nonreportable underground fires by ignition source

Ignition source	Incidents
Electrical	15
Friction	10
Unspecified	1

NOTE.--χ^2 = 1.0 (not statistically significant at the 0.05 level of confidence).

Fires by Substance Burning

Table 29, containing the burning substances of nonreportable fires, lists the most frequent burning substance as wiring insulation. Coal, primarily loose coal or coal dust, was the second most frequent burning substance. The totals for insulation and coal fires are not significantly different.

TABLE 29. - Nonreportable underground fires by substance burning

Substance	Incidents
Insulation	14
Coal	12
Other	2

NOTE.--χ^2 = 0.15 (not statistically significant at the 0.05 level of confidence).

Fires by Location

Locations of nonreportable fires appear in table 30. The most frequent locations were the haulageway and main haulageway, where locomotives, conveyor belts, and shuttle cars are located. Totals for haulageway and main haulageway fires are not significantly different.

TABLE 30. - Nonreportable underground fires by location

Location	Incidents
Haulageway	8
Main haulageway	15
Other	1
Unspecified	2

NOTE.--χ^2 = 2.13 (not statistically significant at the 0.05 level of confidence).

Fires by Equipment Involved

Table 31 contains the equipment involved in nonreportable fires. The most frequently involved piece of equipment was the conveyor belt; shuttle cars and scoop trams had the second highest incidence. Overheated trailing cables caused shuttle car fires, and scoop trams had battery fires. The locomotive had the third highest incidence because of wiring shorts and cable overheat. Totals for the four equipment types are not significantly different.

TABLE 31. - Nonreportable underground fires by equipment involved

Equipment	Incidents
Shuttle car	4
Locomotive	3
Conveyor belt	10
Scoop tram	4
Other	5

NOTE.--χ^2 = 5.86 (not statistically significant at the 0.05 level of confidence).

Fires by Successful Extinguishing Agent or Method

The successful extinguishing agents for nonreportable fires appear in table 32. The most frequently used agent was a hand-portable extinguisher. Other successful methods were water, power disconnection, rock dust, an installed fire control system, and removal of coal. Totals for the six extinguishing agents are not significantly different.

TABLE 32. - Nonreportable underground fires by successful extinguishing agent or method

Agent	Incidents
Portable extinguisher	11
Water	9
Rock dust	7
Installed system	2
Removal of coal	2
Power disconnection	8
Unspecified	1

NOTE.--χ^2 = 10.69 (not statistically significant at the 0.05 level of confidence).

Surface Fires

Fires by Ignition Source

Ignition sources of nonreportable fires listed in table 33 indicate that the top two sources were electrical and cutting torch. Electrical fires were generally caused by wiring shorts that ignite leaking hydraulic fluid or diesel fuel. Cutting torch fires generally ignited accumulations of oil and grease. Other ignition sources were friction and turbocharger or engine manifold. Incident totals for the different ignition sources differ significantly.

TABLE 33. - Nonreportable surface mine fires by ignition source

Ignition source	Incidents
Cutting torch	10
Electrical	17
Friction	4
Turbocharger manifold	4
Engine manifold	4
Other	4
Unspecified	3

NOTE.--χ^2 = 17.03 (statistically significant at the 0.01 level of confidence).

Fires by Substance Burning

Table 34 contains the burning substances involved in nonreportable fires. The most frequently involved categories were oil and grease, hydraulic fluid,

and diesel fuel, which collected on surfaces and were ignited by cutting torches and electrical arcs. Other burning substances were coal, wiring insulation, transmission fluid, and ether. Totals for the burning substance categories differ significantly.

TABLE 34. - Nonreportable surface mine fires by substance burning

Substance	Incidents
Diesel fuel	7
Oil and grease	14
Insulation	5
Transmission fluid	2
Hydraulic fluid	8
Ether	2
Coal	6
Other	5

NOTE.--χ^2 = 16.14 (statistically significant at the 0.05 level of confidence).

Fires by Location

Table 35 presents locations of nonreportable fires. The overwhelming majority of fires occurred on mobile machinery; other fires occurred in the maintenance shop and on conveyor belts. Fire incident totals for the locations differ significantly.

TABLE 35. - Nonreportable surface mine fires by location

Location	Incidents
Mobile machinery	36
Maintenance shop	3
Conveyor belt	3
Other	4

NOTE.--χ^2 = 51.86 (statistically significant at the 0.01 level of confidence).

Fires by Equipment Involved

Table 36 contains nonreportable fires by equipment involved. The highest number of fires occur on draglines, bulldozers, and haulage trucks. These fires generally involved accumulated oil, grease, and diesel fuel ignited by cutting torches, engine heat, or wiring shorts. Other equipment involved were the drill, front-end loader, conveyor belt, shovel, and scraper. Because of the large number of equipment types involved, the incident totals do not differ significantly.

Fires by Successful Extinguishing Agent or Method

Successful extinguishing agents for nonreportable fires appear in table 37. The overwhelming majority of these fires were extinguished with hand-portable extinguishers. Other extinguishing agents were water, wheeled

extinguishers, and self-extinguishment. The totals for the extinguishment types differ significantly.

TABLE 36. - Nonreportable surface mine fires by equipment involved

Equipment	Incidents
Dragline	8
Front-end loader	3
Haulage truck	6
Bulldozer	7
Shovel	2
Scraper	2
Drill	4
Conveyor belt	3
Pickup truck	2
Other	7
None	2

NOTE.--χ^2 = 9.35 (not statistically significant at the 0.05 level of confidence).

TABLE 37. - Nonreportable surface mine fires by successful extinguishing agent or method

Agent	Incidents
Hand-portable extinguisher	35
Water	2
Wheeled extinguisher	2
Self-extinguishing	2
Other	4
Unspecified	3
None	1

NOTE.--χ^2 = 79.68 (statistically significant at the 0.01 level of confidence).

Opinion Data

Underground Fires

Table 38 contains ignition sources, burning substance, and cause for underground nonreportable fires. Each item is listed according to the average rank assigned to it by the safety directors interviewed. The top 5 ignition sources were electrical, friction, spontaneous combustion, engine heat, and cutting torch. The top six burning substances were wiring insulation, coal, grease, clothing, conveyor belt, and welding equipment. The top six causes of fires were poor maintenance, infrequent inspection, spontaneous combustion, poor housekeeping, operator error, and poor equipment design.

Table 39 lists equipment most likely to be involved in underground nonreportable fires. The top six pieces of equipment were conveyor belt, shuttle car, locomotive, batteries, undercutter, and a pump or its motor.

TABLE 38. - Underground fires opinion data--average rankings for ignition source, burning substance, and cause

Rank	Ignition source	Burning substance	Cause
1	Electrical	Wiring insulation.	Poor maintenance.
2	Frictional	Coal	Infrequent inspection.
3	Spontaneous combustion.	Grease	Spontaneous.
4	Engine heat	Clothing	Poor housekeeping.
5	Cutting torch	Conveyor belt	Operator error.
6	-	Welding equipment.	Poor equipment design.

TABLE 39. - Underground fires opinion data--average rankings for equipment involved

Rank	Equipment	Rank	Equipment
1	Conveyor belt.	7	Roof bolter.
2	Shuttle car.	8	Welding equipment.
3	Locomotive.	9	Hoist.
4	Batteries.	10	Rectifier.
5	Undercutter.	11	Transformer.
6	Pump or motor.		

Surface Fires

Table 40 contains ignition source, burning substance, and cause for surface nonreportable fires. Each item is listed according to the average rank assigned to it by the safety directors interviewed. The top five ignition sources were engine heat, cutting torch, electrical, friction, and spontaneous combustion. The top six burning substances were oily rags, grease, hydraulic fluid, diesel fuel, wiring insulation, and coal. The top five causes of fires were poor maintenance, operator error, poor equipment design, infrequent inspection, and spontaneous combustion.

TABLE 40. - Surface mine fires opinion data--average rankings for ignition source, burning substance, and cause

Rank	Ignition source	Burning substance	Cause
1	Engine heat	Oily rags	Poor maintenance.
2	Cutting torch	Grease	Operator error.
3	Electrical	Hydraulic fluid	Poor equipment design.
4	Frictional	Diesel fuel	Infrequent inspection.
5	Spontaneous combustion.	Wiring insulation.	Spontaneous.
6	-	Coal	Arson.

Equipment involved in surface fires appears in table 41. The top six pieces of equipment were the front-end loader, dragline, haulage truck, bulldozer, stripping shovel, and scraper.

TABLE 41. - Surface mine fires opinion data--average rankings for equipment involved

Rank	Equipment	Rank	Equipment
1.....	Front-end loader.	7.....	Loading shovel.
2.....	Dragline.	8.....	Drill.
3.....	Haulage truck.	9.....	Grader.
4.....	Bulldozer.	10.....	Silo.
5.....	Stripping shovel.	11.....	Transformer.
6.....	Scraper.	12.....	Conveyor belt.

General Opinions

After interviewing the safety directors on unreportable fires, the researchers agreed on the following points: The primary cause of nonreportable underground fires was poor housekeeping and maintenance. When mining equipment was poorly maintained and allowed to develop a coating of hydraulic fluid, grease, and coal, an electrical short eventually ignited the accumulated flammable substances. The primary cause of nonreportable surface fires was poor equipment design, poor maintenance, and poor housekeeping. Surface mining equipment that was poorly designed leaked hydraulic fluid and oil in great quantities. The fluid and oil then collected in hard-to-reach locations, where the equipment operator allowed it to remain; it was eventually ignited by a cutting torch or electrical short.

Nonreportable Fires Extinguishment Success

Although a fire extinguished without injury in less than 30 minutes is nonreportable, fires that involve an injury or last 30 minutes or more must be reported to MSHA and should be documented in a fire report. By comparing reportable and nonreportable fires at the mines where safety directors were interviewed, a rough estimate of the percentage of fires extinguished at the nonreportable stage can be obtained.

Table 42 contains the number of reportable and nonreportable fires at the mines visited. Reportable fires represent the number of MSHA fire reports located for the mines visited. Because the opinion data covered the last 5 years, only fire reports over 1973 through 1977 were counted. Many of the nonreportable fire incidents have multiple occurrences. However, these incidents have multiple occurrences. However, these incidents tend to be trivial fires and were counted as a single event. As shown in table 42, underground mines appeared to be successful in extinguishing almost 70 pct of their fires at the nonreportable stage, and surface mines appear to be approximately 90 pct successful.

TABLE 42. - Fire extinguishment at nonreportable stage, estimated success

1973-77	Underground	Surface
Nonreportable fires.....	26	46
Fire reports.....	9	5
Ratio.....	3:1	9:1
Estimated success rate.....pct..	67	89

CONCLUSIONS

Major Results

Major findings of the study appear in table 43. The most frequent ignition sources, burning substances, equipment types, locations, and extinguishing agents of reportable and nonreportable fires are discussed separately below.

Ignition Sources

The overwhelming majority of reportable and nonreportable underground mine fires were electrical. Electrically ignited fires were the primary cause of underground fire injuries and the only cause of underground fire fatalities.

The top three ignition sources were electrical, spontaneous combustion, and friction for reportable underground fires, and ignition sources were electrical, welding, and spontaneous combustion for reportable surface fires. Injury fires underground and on the surface were caused by electrical and welding ignition sources. Fatal underground fires were electrical, and fatal surface fires were welding or open flame in origin.

In underground mines where primary power is electrical, most fires, most injuries, and all fatal fires were electrical. In surface mines where the primary power is diesel, most fires were electrical, but most injury and fatal fires were caused by welding.

Burning Substance

The most frequent burning substance in underground mines was wiring insulation for both reportable and nonreportable fires. For surface mines, the most frequent burning substance in reportable fires was timber or wood (buildings), and in nonreportable fires it was oil and grease (on mobile vehicles).

Equipment Involved

The most frequent equipment involved in underground fires was the conveyor belt for both reportable and nonreportable fires. Welding equipment was the highest ranking equipment type for underground injury fires, because electrical fires were distributed across a number of equipment types.

Reportable surface fires involved structures and buildings, and nonreportable surface fires involved mobile equipment. Vehicle fires were more quickly detected and reached with hand-portable extinguishers because there was less structure to collect the smoke.

TABLE 43. - Major study findings

(Factors listed in sequence of significance)

Category	Reportable fires					
	Underground			Surface		
	Overall	Injury	Fatal	Overall	Injury	Fatal
Ignition source..	Electrical, spontaneous, friction.	Electrical, welding.	Electrical.	Electrical, welding, spontaneous.	Welding, electrical.	Welding, open flame.
Burning substance	Wiring insulation, coal, rubber.	([1])	([1])	Timber and wood, coal, rubber.	([1])	([1])
Equipment involved.	Belt, cutter, locomotive.	Welding.	([1])	Crusher and/or breaker, tipple, cleaning plant.	([1])	([1])
Location.....	Outby face, working face, haulageway.	Outby face, haulageway.	Outby face, working face.	Tipple, crusher and/or breaker, cleaning plant.	([1])	([1])
Successful extinguishing agent.	Water, dry chemical, rock dust.	([1])	([1])	Water, dry chemical, rock dust.	([1])	([1])

	Nonreportable fires			
	Incident descriptions		Opinion data	
	Underground	Surface	Underground	Surface
Ignition source..	Electrical, friction.	Electrical, welding.	Electrical, friction spontaneous.	Engine heat, cutting torch, electrical.
Burning substance	Wiring insulation, coal.	Oil and grease, hydraulic fluid, diesel fuel.	Wiring insulation.	Oily rags, grease, hydraulic fluid.
Equipment involved.	Conveyor belt, shuttle car, scoop tram.	Dragline bulldozer, haulage truck.	Conveyor belt, shuttle car, locomotive.	Front-end loader, dragline, haulage truck.
Location.....	Main haulageway, haulageway.	Mobile machinery, maintenance shop, conveyor belt.	([1])	([1])
Successful extinguishing agent.	Portable extinguisher, water, power disconnection.	Portable extinguisher, water, self-extinguishing.	([1])	([1])

[1]Factors not (statistically) significantly different from "overall" square.

Location

Reportable underground fires occurred near the working face where powerful electrical equipment (with oil and grease accumulations) is concentrated, along with employees. Welding was also done by the face. Nonreportable fires occurred in the haulageways where belts and locomotives had more short-duration fires.

Fire location data for surface mines agreed with the equipment data. Reportable fires occurred primarily in structures, and nonreportable fires occurred primarily in mobile equipment.

Successful Extinguishing Agent

The most successful extinguishing agent for reportable fires was water, and for nonreportable fires it was hand-portable extinguishers. This is because the first attempt to extinguish a fire was generally with a hand-portable extinguisher. If the attempt was successful, then the fire was extinguished at the nonreportable stage; if the attempt was unsuccessful, then the fire probably lasted more than 30 min and became reportable while water was brought to the area and applied to the fire.

Recommendations

As a result of the data analysis, a number of conclusions were developed. These conclusions and some recommendations are discussed below under fire rates, fire reporting, electrical equipment, equipment design, maintenance, housekeeping, and training.

Fire Rates

Fire incidence rates have been declining since 1960, and the rate was significantly lower in the 1970-77 period than in the 1960-69 period. Like most rates that cannot have a negative value, as the curve approaches zero it begins to asymptote, and no significant downward trend is apparent in the post-1970 data.

Fire Reporting

Some personnel contacted during the study indicated that Federal regulations should be modified to require the reporting of all fires. Fires that are currently nonreportable would be listed in a letter report with a two- or three-sentence description indicating ignition source, burning substance, duration, and extinguishing agent.

Electrical Equipment

As stated above, the primary cause of underground fires was electrical. A major portion of electrical fires involved DC trailing cables. One of the underground mines visited during the study used AC power for its mining equipment and had a surprisingly low fire incidence rate. Safety directors at

other mines indicated that AC power was known to be less fire-prone, but multi-conductor trailing cables were difficult to splice and dual reels for dual cables were not very effective. Work is in progress to solve these problems, and their elimination will facilitate a changeover to AC power in underground mines. A significant reduction in fire related fatalities should result.

Equipment Design

Equipment design is a major factor in the cause of mine fires. A large portion of underground vehicles have electric wiring routed in close proximity with hydraulic hoses where hydraulic fluid from leaking or ruptured hoses is likely to come into contact with shorts in the electrical wiring. Equipment designers should separate hydraulic hoses from electrical wiring and other ignition sources.

On surface mining equipment, the primary problem is leaking hydraulic lines. Because of high pressures, hydraulic lines in draglines and shovels leak hugh quantities of fluid that is later ignited by electrical shorts or welding. Equipment designers must make a concerted effort to reduce leaks in their equipment. In addition, equipment should be designed to facilitate access to likely collection points so the oil can be removed periodically.

Maintenance

The primary cause of fires is poor maintenance. Most mining equipment is not repaired until it stops working, such as hydraulic hoses that crack and start to leak but are left in service until they rupture. When couplings and hoses leak, the hydraulic fluid tank is continually refilled instead of the leaks being repaired; thus, mining equipment generally has a coating of hydraulic fluid, oil, and coal waiting for the next ignition source. This will continue until mine management places a higher priority on maintenance.

Another poorly maintained item is fire detection and suppression systems. They must be properly inspected and maintained if they are to function when the need arises.

Housekeeping

Until equipment design and maintenance improve, good housekeeping will be required to reduce the hazard from fires. Equipment operators must be trained to notify the maintenance department when leaks occur on their equipment and they should be required to clean their equipment during production delays. A concerted housekeeping effort would reduce the buildup of flammables on mining equipment and thereby lower the likelihood and reduce the severity of fires.

Training

If miners were better trained, more fires would be extinguished at the nonreportable stage. It is critical that miners be trained in firefighting because they are the only ones who can attack the fire while it is small. By the time firefighting experts can be brought in, the fire is likely to be out of control. The miners should be aware of fire regulations and the importance of their enforcement.

During general orientation, the miners should be instructed on the most likely causes of fires, how to detect one, how to approach the fire without injury, how to remove electrical power, how to use hand-portable extinguishers, when to retreat, and who to notify. This information could be taught in a short time and would result in significant reductions in reportable fires.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-603-102/88

INT.-BU.OF MINES,PGH.,PA. 24808

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